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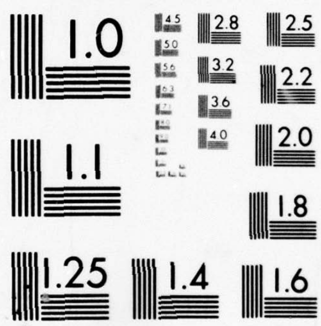

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FINAL REPORT

ON

CONTRACT N00039-76-C-0326

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ON

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Prepared for:
Naval Electronic Systems Command

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Partial CONTENTS;

Section 1
INTRODUCTION AND SUMMARY

This Final Report summarizes work performed by Science Applications, Inc. for the Naval Electronic Systems Command under Contract N00039-76-C-0326. The original contract called for work related to improving the parabolic-equation model and the acquisition of surface-ship source-level data. Subsequent modifications and extensions included tasks related to technical support for SURTASS ISST.

The specific tasks and associated technical reports are listed below along with a brief statement of results:

Task I - Extension of the Parabolic Equation Model to High Angles

An algorithm has been developed and tested which significantly improves the treatment of high-angle bottom-bounce propagation in the Parabolic-Equation Model.

Reference 1: Lewis B. Dozier and C. W. Spofford, "Extensions of the Parabolic Equation Model for High-Angle Bottom-Interacting Paths," SAI Report 78-712-WA, dated December 1977.

Task II - Feasibility of Acquiring Surface-Ship Source-Level Data Using the ARC

The feasibility of broadband tracking surface ships and accurately estimating surface-ship source levels has been demonstrated on a component-by-component basis.

The restricted measurement sites available to the ARC during the period of research prevented a direct demonstration.

Reference 2: J. S. Hanna, "Final Report on Feasibility Study to Determine Surface Ship Source Levels from ARC Data (U)," SAI Report 78-233-WA, dated December 1977 (SECRET).

Additional supporting references:

Reference 3: J. S. Hanna, "Travel-Time Differences from a Broadband Source for Pairs of Sensors," SAI Report 78-708-WA, dated December 1977.

Reference 4: L. S. Blumen, "Documentation of PDP 11/70 Software for Determining Travel-Time Differences from Cross Covariances," SAI Report 78-713-WA, dated December 1977.

Reference 5: J. Czika, "A Study of Ship Track Parameter Estimation," SAI Report 78-707-WA, dated December 1977.

Tasks III & IV - Technical Support for SURTASS ISST

SAI provided technical support in developing the SURTASS ISST data Analysis Plan and in subsequent analysis, and provided a chief scientist for sound-source support onboard USNS KINGSPORT. The final report on this work is:

Reference 6: J. S. Hanna, "Final Report SURTASS Support Tasks," SAI Report 78-680-WA, October 1977.

Additional supporting references:

Reference 7: J. S. Hanna "Recommendations for Acoustic Tests of SURTASS (U)," SAI Report 78-215-WA, dated March 1977 (CONFIDENTIAL).

Reference 8: P. V. Rost, "ISST June 1977 USNS KINGSPORT Trip Report (U)," SAI Report 78-227-WA, dated August 1977 (SECRET).

The approach, results, and conclusions in each of these tasks is summarized in the following sections and described in detail in the supporting references. Specific recommendations made relating to Tasks I and II are:

1. The algorithm for extending the parabolic-equation model to higher-angle bottom-interacting paths should be incorporated in production versions of the code.

2. Data from measurement sites closer to heavy shipping lanes should be acquired (and certain minor modifications to ARC display software made to support this acquisition) to directly demonstrate the tracking and source-level measurement technique.

Section 2
TASK I: SUMMARY OF PARABOLIC EQUATION TASK

This section summarizes the results of work performed in the area of improving the parabolic-equation (PE) model's treatment of high-angle bottom-interacting paths. The parabolic equation method is an area of extremely active research. Hence, work on this contract has attempted to avoid duplicating on-going efforts elsewhere by shifting the emphasis from improvements originally proposed to related but different improvements.

Specifically, an extension of PE to higher angles of propagation was sought which would effectively address important bottom-interacting paths, too steep for present algorithms. The original intent was to focus on limited domains of high-angle propagation by integrating directly the elliptic wave equation. Work in this area at other laboratories had progressed to the point that the emphasis was shifted to approximate solutions practical over larger domains. Such a technique has been developed which has a known, controllable accuracy, adequate for many applications. The options considered and the rationale for the approach adopted are discussed below.

2.1 Background and Options

The recognized most powerful low-frequency long-range propagation-loss model currently applied to Navy problems is the parabolic-equation model. Since its introduction four years ago by Tappert, it has been evaluated against numerous data sets, improved in certain areas, and

significantly streamlined by AESD. It has proven an extremely accurate and effective tool for predicting and analyzing low-frequency propagation for range-dependent environments. For propagation paths which do not interact with the ocean bottom, the model accuracy is limited only by the accuracy of the input sound-speed structure. In comparisons with several sets of LRAPP data where concurrent environmental and acoustic data were obtained, apparent model errors were within achievable measurement accuracy.

The primary limitation of the parabolic-equation method (beyond the practical high-frequency limit of ~ 300 Hz) is that the underlying approximations become inaccurate for moderate propagation angles (10 to 20 degrees), and break down for steeper angles. It has been shown* that the moderate-angle limitation can be largely eliminated by a transformation ("CMOD") of the sound-speed profile. The steeper angles remain a problem of critical importance to the following propagation areas:

(1) Propagation to a slope-mounted receiver where signfiicant long-range refracted and RSR energy converts to high angles by reflecting once or twice off the slope in front of the receivers;

(2) Propagation from sources over shoaling water such as continental slopes where

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*H. K. Brock, R. N. Buchal, and C. W. Spofford, "Modifying the Sound-Speed Profile to Improve the Accuracy of the Parabolic Equation Technique," J. Acoust. Soc. Am. 62 (1977) pp. 543-552.

steep angles reflect once or twice off the downslope converting to shallow-angle low-loss paths (the so-called "megaphone" effect).

(3) Propagation over seamounts and other localized high-reflectivity features where shallow paths reflect into steep paths on the incident upslope and convert back to shallow paths after reflection on the downslope.

(4) Propagation over regions whose sea-floors are characteristically unconsolidated sediment where high-angle paths refract in the sediment with very little loss and propagate to great ranges with significant energy.

In all but the last case, the important regions of high-angle propagation are limited to tens of miles out of total propagation lengths of hundreds to thousands. Direct numerical integration of the full elliptic wave equation is generally impractical for such long tracks. It was originally intended to study such an approach limited to these isolated high-angle regions and coupled to the parabolic-equation algorithm in between. Such a technique might solve three of the four problems listed above.

Brock, now at NRL, has been pursuing such an approach and has demonstrated its feasibility in the context of the Texas Instruments Advanced Scientific Computer (TI-ASC).

He factors the elliptic operator into the product of an outgoing-wave operator and a backscattered-wave operator, each valid for arbitrarily high angles, and then solves only for the outgoing wave (neglecting backscatter) using a marching finite-difference technique. While the approach is feasible on the TI-ASC, it does not appear to be practical for standard third-generation computers.

We then focused on several potentially more efficient approaches:

(1) Retention of more terms in the expansion of the outgoing-wave operator but maintaining the split-step FFT (vice finite-difference) integration algorithm.

(2) Alternative operators, closer to the elliptic operator but amenable to the split-step integration.

(3) Propagation of higher angles in terms of the plane-wave Fourier components (up- and down-going).

The first approach, while feasible, appears to offer at most modest increases in angular aperture. The second has been extensively investigated by Tappert,* who reports new results accurate for either high angles with weak gradients (cf. his Eq. (3.38)), or shallow angles with strong gradients (cf. his Eq. (3.46)). Since our problem involves both high

*F. D. Tappert, "The Parabolic Approximation Method," in Lecture Notes in Physics No. 71, edited by J. B. Keller and J. Papadakis (Springer-Verlag, New York, 1977).

angles <u>and</u> steep gradients, Tappert's result is not sufficient; however, its precise limits should be investigated. The third approach has been analyzed and reported by Estes and Fain* in an extended version. It appears to be sufficiently cumbersome that it may be impractical for routine applications.

2.2 The Problem

As these results emerged, our research shifted to the more difficult, fourth problem: high-angle propagation over large regions. While the approaches described above might prove feasible for limited domains, the long-range problem clearly required some compromises.

An approach similar to the PE CMOD was adopted: modify the environment so that the solution using PE in this environment more closely approximates the wave-equation solution for the original environment. Specifically, the refracting properties of the ocean bottom as specified by the user are modified so that the bottom interacting rays when traced under PE would have the some periods as their elliptic-equation counterparts in the original problem. In effect the range-error accumulated by the high-angle rays in the water column is offset by reducing the distance spent in the bottom through a modification to the sound-speed profile in the bottom.

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*L. E. Estes and G. Fain, "Numerical Technique for Computing the Wide-Angle Acoustic Field in an Ocean with Range-Dependent Velocity Profiles," J. Acoust. Soc. Am. <u>62</u>, 38-43 (1977).

2.3 Results

As reported in Reference 1, this approach has been developed and tested with PE, demonstrating its feasibility. Its principal benefits are

(1) Rays at high angles propagate with the correct periods, thus interacting with the appropriate portions of the bottom on each bounce and accumulating the correct number of bounces at any given range,

(2) In implementation it is applied, like CMOD, to the specified environment and has no impact on the efficiency of the split-step FFT algorithm itself (beyond the need for smaller depth and range increments resulting from higher angles and stronger gradients).

Its limitations are:

(1) While it does preserve ray periods, a small one-time-only range error is present on high angle rays.

(2) The detailed multipath interference patterns generated by PE will still reflect the phase velocity error of the parabolic approximation.

(3) The bottom must be modelable as a refracting medium vice a reflecting surface.

(4) Detailed variations in bottom properties will only be approximately treated.

The benefits are felt to outweigh the limitations, and the approach appears to have sufficient accuracy for enough applications that we recommend its incorporation in production versions of PE. Reference 1 addresses the detailed considerations associated with such an implementation (which was beyond the scope of this feasibility study).

Section 3
TASK II: SUMMARY OF SURFACE-SHIP SOURCE-LEVEL MEASUREMENT TASK

The objective of this task was to examine the feasibility of using existing bottomed hydrophone arrays to obtain data on surface ship source levels. Such a capability might provide an attractive alternative to present sonobuoy collection techniques both in cost (eliminating the need for airplanes) and quality (providing vertical directionality critical to ambient-noise modeling and distributed-system performance). The proposed approach would broadband track surface-ships using travel-time differences on pairs of hydrophones to estimate track parameters. From the track and the received level the source level would be estimated.

As described in Reference 2, the key aspects of the feasibility study have been successfully demonstrated:

(1) Signal processing algorithms to estimate travel-time differences have been developed, implemented and tested on data acquired at the ARC. (See also supporting References 3 and 4.)

(2) A capability to estimate track parameters (and associated errors) from such data has been developed and used to identify key sensitivities in the tracking problem (Reference 5).

Because the ARC could provide data from only one site (with substantially lower surface-ship traffic than the desired site) no data could be obtained for ships sufficiently close to track and measure source levels. Present limitations in the ARC display capabilities made this conclusion possible only after extensive data analysis (rather than upon real-time inspection of displays).

As a result, the use of existing bottomed systems to accurately measure surface-ship source levels appears feasible, but has only been partially demonstrated. It is recommended, therefore, that the capability be fully demonstrated by acquiring data from a more suitable site (with appropriate real-time ARC displays available) and analyzing the data with the signal processing and tracking algorithms which have been developed.

Section 4

TASKS III AND IV: SUMMARY OF SURTASS TECHNICAL SUPPORT

These tasks were added to the subject contract by PME-124/40. Task III called for support in development of measurement techniques to establish the acoustic performance of SURTASS. The specification of these techniques is contained in Reference 7. Task IV called for participation in the preparation of the ISST exercise and data analysis plans and to provide the chief scientist for the USNS KINGSPORT. Documentation of this work is contained in Reference 8. Reference 6 represents the final report for these tasks.

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